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MILITARY HANDBOOK

HANDBOOK FOR PAINTS AND PROTECTIVE COATINGS  
FOR FACILITIES



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ABSTRACT

This handbook is provided as guidance for DOD personnel wishing to apply architectural paints or protective coatings to military structures fixed in place. It is not for use with ships, aircraft, or automotive vehicles. It is written for general use by both those with much and with little knowledge of the use of paint and coating materials. It contains information on the composition of coatings, their mechanisms of curing, environmental and safety concerns, necessary surface preparation, selection for different substrates and structures, application, inspection, and failure analysis.

FOREWORD

This handbook identifies criteria and procedures for applying architectural paints or protective coatings to military structures fixed in place.

Recommendations for improvements are encouraged from Government agencies and the private sector and should be furnished on the DD Form 1426 provided inside the back cover to Commanding Officer, Northern Division, Naval Facilities Engineering Command, Code 164, 10 Industrial Highway, Mail Stop 82, Lester, PA 19113-2090; Telephone: Commercial (610) 595-0661/DSN 443-0661.

THIS HANDBOOK SHALL NOT BE USED AS A REFERENCE DOCUMENT FOR PROCUREMENT OF FACILITIES CONSTRUCTION. IT IS TO BE USED AS A MAINTENANCE MANAGEMENT TOOL BY PUBLIC WORKS DEPARTMENTS, PUBLIC WORKS CENTERS, BASE CIVIL ENGINEERS, AND FACILITIES ENGINEERS. DO NOT REFERENCE IT IN MILITARY OR FEDERAL SPECIFICATIONS OR OTHER PROCUREMENT DOCUMENTS.

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## Section 1: INTRODUCTION

1.1 Purpose. This handbook presents information on the effective use of paint-type coatings to protect metal, concrete, and wooden structures at military activities from deterioration. In this handbook, the words "paint" and "coating" are used interchangeably. Sometimes, the word "paint" is used to describe an architectural rather than protective material, but this is not the case in this handbook.

1.2 Scope. This handbook covers virtually all aspects of coating fixed structures. These include surface preparation for painting; selection, application, and inspection of coatings for both original and maintenance painting; quality control methods and equipment; and painting different substrates and facilities. It does not cover painting of ships, aircraft, or motor vehicles. The coatings covered are limited to organic paint-type materials, with a few exceptions. Inorganic zinc, thermal spray metal, and powder coatings are included, because they are most commonly used as alternatives to conventional organic coatings and, like organic coatings, are usually applied by spray.

1.3 Deterioration of Facilities. The main purpose of painting military facilities is to protect them from deterioration. These structures comprise a vital resource in the defense of our nation. They must be kept in a state of operational readiness by efficient use of the limited funds available for this purpose. Unfortunately, these facilities are frequently subject to environments and uses that accelerate their natural deterioration and require costly repairs and maintenance. Metals corrode in aggressive soil, industrial or chemical atmospheres, or immersion environments; woods swell, warp, and crack during weathering; concrete and masonry structures crack and spall in severe environments; and organic polymeric materials suffer degradation in sunlight. To adequately meet the challenges of protecting constructed facilities, it is necessary to have a general understanding of the common ways in which materials deteriorate and the procedures used to control the deterioration.

1.3.1 Corrosion of Metals. Metals corrode because they exist in chemically unstable states. Thus, iron ore is a corrosion product in its natural, stable state. Energy must be used in blast furnaces to reduce iron to its metallic state. Iron and steel products are then slowly oxidized by corrosion to their previous stable lower energy states. Four conditions must be present for corrosion to occur:

- a) Anodic areas where corrosion occurs

- b) Cathodic areas where the metal is protected
- c) An electrolyte (conductive medium such as soil or water)
- d) A metallic path between the anode and cathode

In atmospheric corrosion, surface moisture and contamination serve as the electrolyte. Dissimilar metals are anodic and cathodic to each other; also, the same metal components have anodic and cathodic areas because of slight chemical or physical differences.

1.3.2 Deterioration of Wood. The chief causes of deterioration of wood are effects of ultraviolet light, and swelling and contracting. These adversely affect the physical properties of the wood.

1.3.3 Deterioration of Concrete. The chief cause of concrete deterioration is moisture and electrolyte penetration. This may result in deterioration of the concrete itself or in corrosion of reinforcing steel which causes spalling of the concrete.

1.3.4 Design Factors Affecting Deterioration. Poor design of structures may accelerate their deterioration or interfere with their protection by coatings. Examples of poor designs are listed below:

- a) Water traps
- b) Crevices
- c) Rough and sharp surfaces
- d) Limited access
- e) Incompatible environment
- f) Contact of dissimilar metals

1.3.4.1 Water Traps. Since water greatly accelerates deterioration, structures should be designed so that water is not collected. For example, angle irons and other configurations that can collect water should be oriented downward rather than upward. Weep holes of sufficient size should be placed where water collection cannot be otherwise avoided. Condensate water from air conditioners should not be allowed to run or drip on surfaces and steam or other vapors should not be allowed to impinge on surfaces.

1.3.4.2 Crevices. Crevices should be avoided in structures, because these oxygen-deficient areas accelerate metal corrosion. Thus, continuous welds should be used rather than skip welds. Back-to-back angles should also be avoided for this reason.

1.3.4.3 Rough and Sharp Surfaces. To obtain protection of a surface, a painter must be able to apply a uniformly thick, continuous film. Thus, irregular surfaces such as welds and other projections should be ground smooth to eliminate projections through the paint film. Weld-spatter, which is loosely-bonded to the steel, must be removed for two reasons. First, it creates crevices which lead to crevice corrosion and, second, as the mill scale becomes disbonded, the barrier film will be broken.

Sharp edges should be rounded (1/8 inch or more radius is ideal) because a uniformly thick coating cannot be applied over the edge. This is because wet coatings draw thin on them. Sharp interior corners should be avoided, since they may receive an excessive coating thickness.

1.3.4.4 Limited Access to Work. Areas to be protected should be readily accessible for inspection and maintenance. Difficult-to-reach areas are not only difficult to prepare and coat, but reaching them may also constitute a safety hazard.

1.3.4.5 Incompatible Environment. Materials must be compatible with the environment in which they are located. Thus, aluminum should not come into direct contact with concrete, because the alkalinity of the concrete will attack the aluminum.

1.3.4.6 Contact of Dissimilar Metals. Dissimilar metals probably present the biggest design problem. Because they have different corrosion potentials, they may corrode rapidly when in contact with each other. Examples of dissimilar metal (galvanic) corrosion are:

- a) Steel pipe passing through an aluminum deck
- b) Steel nut on a copper valve
- c) Aluminum stanchion with a bronze lifeline
- d) Aluminum plate with steel or different alloy aluminum rivets
- e) Mild steel attached to stainless steel

Dissimilar surface conditions (e.g., threads, scratches, etc.) may also cause galvanic corrosion.

1.4 Control of Facilities Deterioration. While coating of surfaces is the most commonly used method of protecting them, it can be used most effectively in conjunction with other control methods. These include but are not limited to proper design of components, proper selection of materials and components, cathodic protection, controlling the environment, and use of corrosion inhibitors.

1.4.1 Corrosion Control by Coatings. Coatings protect metals from corrosion by interfering with one or more of the conditions necessary for corrosion to occur. The three protective mechanisms of coatings are:

- a) Barrier
- b) Inhibitors
- c) Cathodic protection

Regardless of the mechanism(s) of protection imparted by coatings, a multiple coat system is normally recommended for maximum protection of metals. The primer is formulated to bond well to the substrate and provide a good surface for adhesion of additional coats. Zinc or inhibitive primer pigments can provide corrosion control, as described above. Intermediate coats provide additional barrier protection and unite the primer and finish coats. The finish coat provides additional barrier protection as well as resistance to weathering, and color, texture, and gloss.

1.4.1.1 Barrier Protection. Most coatings provide corrosion protection by forming a barrier that is relatively impermeable to moisture and electrolytes (usually salts) necessary for corrosion. No organic coating is completely impermeable, but some are much more so than others. Obviously, the coating film must be thick enough and free of discontinuities (holidays) to achieve maximum barrier protection.

1.4.1.2 Inhibitive Pigments. Some pigments are used in primers for metals to inhibit the corrosion reaction at the metal/primer interface. Red lead and zinc chromate pigments, used for this purpose for many years, are seldom used today because of health and environmental concerns. Acceptable alternate corrosion control pigments are available.

1.4.1.3 Cathodic Protection. Some coatings have a high loading of fine zinc particles to provide cathodic protection to steel surfaces. They convert anodic areas on the steel to cathodic areas. The zinc particles must be in electrical contact with

each other and with the steel to provide this protection. The two basic types of zinc-rich coatings, organic and inorganic zinc, will be described later in this handbook.

A film of inorganic zinc silicate coating is unique because the film is relatively porous. Initially, the coating protects steel by cathodic protection, but its corrosion products gradually fill the porosity, so that it becomes a barrier coating. Should this barrier coat become scratched to expose the steel substrate, cathodic protection will begin again until the damage is healed. An inorganic zinc silicate coating is also unique in that it reacts with the steel to form a chemical bond. Many organic coatings rely on physical rather than chemical bonding to steel.

#### 1.5 Painting for Purposes Other Than Protection.

Facilities are often painted for other purposes than, or in addition to, protection. These include appearance, marking, and safety.

1.5.1 Cosmetic Appearance. Painting is an important factor in promoting morale and productivity. NAVFAC P-309, Colors for Navy Shore Facilities, and Army TM5-807-7, Color for Buildings, present scientific approaches to the use of color to improve working and living environments.

FED-STD-595, Colors Used in Government Procurement, presents standard colors currently used by the Government. The colors are identified by five-digit numbers, and defined by fundamental color data. The standard, also available as a fandeck, includes reference chips of each color.

1.5.2 Marking Paints. Marking paints are used on airfield runways, streets, and parking lots. Their chief function is to provide safety for personnel and equipment.

1.5.3 Safety Colors and Designs. Safety colors and designs are used on military installations for rapid identification of hazards or safety equipment. They are also described in NAVFAC P-309.

1.5.4 Reflective Finishes. Reflective finishes on concrete floors of hangars and shops may increase the lighting for workmen, particularly in sheltered areas such as under the wings of aircraft. Such smooth floors are easier to keep clean.

1.5.5 Nonskid Surfaces. Nonskid surfaces are frequently made by adding grit to coatings on floors, ramps, and other walking surfaces to provide slip resistance.

1.5.6      Antifouling Coatings.    Antifouling coatings prevent the attachment and growth of marine fouling organisms by the controlled release of toxic materials.

## Section 2: COATING COMPOSITIONS AND CURING MECHANISMS

2.1 Coating Composition. The primary ingredients used to formulate coatings can be placed into one of three basic categories - solvent, resin, and pigment. Each of these categories has a special function in the formulation of coatings. The resin (also called binder) and the solvent comprise the liquid portion, sometimes called the vehicle. Since the solvent evaporates as a coating cures, it is sometimes called the volatile vehicle, and the resin the nonvolatile vehicle. The resin and pigment which comprise the solid film after evaporation of the solvent are sometimes called the total solids or film solids.

Historically, the first paints utilized fish or vegetable (e.g., linseed) oils as binders and natural earth pigments. The first solvents were from trees (e.g., turpentine). Now most resins and solvents are derived from petroleum, and many pigments are derived from organic synthesis or modification of natural minerals.

2.1.1 Solvent. Organic solvents are used to dissolve the resin material and reduce the viscosity of the product to permit easier application. They also control leveling, drying, durability, and adhesion. Because the different organic polymers in different formulations vary greatly in their solubilities, some resins require much stronger solvents and/or greater amounts than others to dissolve them. In most water-based coatings, the water is a dispersing rather than a dissolving agent.

A blend of solvents is generally used in paint to achieve all the properties desired from them. The blend must completely dissolve the total binder system and be balanced to ensure compatibility and stability during all stages of curing. Improper blends may result in cloudy films, pigment float to the wet film surface, or reduced film durability.

Paint solvents evaporate into the air and contribute to the production of photochemical smog. Thus, there is a great pressure to reformulate coatings to reduce the solvent content of paints.

2.1.2 Resin. Resins, also called binders, are the film-forming portions of coatings. They are usually high molecular weight solid polymers (large molecules with repeating units) in the cured film. In some cases, lower molecular weight units in two liquid components react with each other upon mixing to polymerize into the higher molecular weight solid.

The resin is responsible for many of the properties of the coating. Thus, coatings are usually identified generically by the types of their resins. Important film properties related to the resin chemistry are:

- a) Mechanism and time of curing
- b) Performance in different environments
- c) Performance on different substrates
- d) Compatibility with other coatings
- e) Flexibility and toughness
- f) Weather resistance
- g) Adhesion
- h) Ease of topcoating and repair
- i) Application properties (wetting, build, pot life, etc.)

2.1.3 Pigment. The pigment constitutes the solid portion of a wet paint. Pigments are insoluble in the vehicle and are generally heavier than the liquid vehicle portion. They may settle to the bottom of a container upon prolonged standing. Natural earth pigments are generally much more stable to light than synthetic organic pigments.

a) The pigment portion of coatings contributes to the following desirable properties:

- (1) Opacity (hiding)
- (2) Color
- (3) Corrosion inhibition
- (4) Weather resistance
- (5) Moisture resistance
- (6) Level of gloss and hardness
- (7) Film build and reinforcement



b) The chief function of the pigment is to provide opacity (hiding) to obscure the substrate and protect the organic resin from degradation by the sun's ultraviolet light. Organic resins degrade to some extent in sunlight, some much more than others. Titanium dioxide is the pigment most frequently used to impart opacity to white paints and light tints, because it has high opacity. If a coat of paint does not completely obscure a surface, it is usually necessary to apply an additional coat.

c) Another important function of some pigments has already been mentioned - corrosion control. Inhibitive pigments can be very effective in reducing the corrosion that would otherwise occur. Lead and chromate inhibitive pigments were commonly used in paints in the past but are now restricted because of adverse health effects. Examples of lead- and chromate-containing pigments, and of those presently used, environmentally acceptable corrosion-inhibitive pigments are listed below:

#### Common Inhibitive Pigments

##### Relatively Hazardous

Red Lead  
White Lead  
Zinc Chromate  
Strontium Chromate  
Basic Lead-Silico-Chromate

##### Relatively Nonhazardous

Zinc Oxide  
Zinc Phosphate  
Zinc Molybdate  
Calcium Borosilicate  
Calcium Phosphosilicate  
Zinc Phosphosilicate  
Barium Metaborate

d) Pigments also may improve adhesion and decrease moisture permeability. Leafing pigments such as aluminum tend to align themselves as parallel plates in the film to effectively increase film thickness by increasing the path that moisture must take to reach the substrate.

e) Other things being equal, the greater the resin-to-pigment ratio, the glossier will be the coating. The size of pigment particles (fineness of dispersion or grind) of the pigment in the vehicle also affects gloss. Other things being equal, the finer the dispersion, the glossier the cured film. Secondary or filler pigments (talc, silica, etc.) are used to control viscosity, wet film build and leveling, and settling. These cheaper pigments provide very little hiding. The pigment to resin ratio, generally expressed as pigment volume concentration (PVC), can vary widely. There can be no pigment, or the pigment content can approach a value called the critical pigment volume concentration (CPVC). As this point is approached, there is insufficient binder to wet the individual

pigment particles and bond them to the substrate. This may result in a poorly bonded or porous film or one with a mottled appearance.

2.1.4 Other Components. There are also many additives used in small amounts in coatings to provide some special function. These include antifoam agents, flattening agents to reduce gloss, mildewcides, adhesion promoters, viscosity modifiers, and ultraviolet stabilizers.

2.1.5 Spreading Rate. If the percent solids by volume of a coating is known, the dry film thickness of a coating can be determined from its wet film thickness by the relationship:

Dry Film

$$\text{Thickness} = \frac{\text{Wet Film Thickness} \times \text{Percent Solids by Volume}}{100}$$

Also, it can be shown mathematically that if 1 gallon of coating is uniformly applied to a flat surface at 1 mil (0.001 inch) wet film thickness, it will cover an area of 1600 square feet. Thus, if the percent solids by volume of a paint is provided by the supplier, its spreading rate at any dry film thickness (dft) can be determined, as shown below:

- |    |                      |   |                               |
|----|----------------------|---|-------------------------------|
| a) | 0 Percent Solvent    | - | 1600 square feet at 1-mil dft |
|    | (100 Percent Solids) |   | 800 square feet at 2-mil dft  |
|    |                      |   | 400 square feet at 4-mil dft  |
| b) | 50 Percent Solvent   | - | 600 square feet at 1-mil dft  |
|    | (50 Percent Solids)  |   | 400 square feet at 2-mil dft  |
|    | by volume            |   | 200 square feet at 4-mil dft  |

Obviously, this relationship is only true for coatings as received from the supplier without thinning. Thinning will reduce the percent solids by volume reported by the supplier and require calculating a new value before the above relationship can be used.

2.2 Mechanisms of Curing of Coatings. Coatings cure from one of three basic ways:

- a) Air oxidation (polymerization) of unsaturated drying oils
- b) Evaporation of solvent from lacquers or water from emulsions
- c) Chemical reaction of components or chemical reaction with water in air

Coatings that cure by solvent or water evaporation are unchanged chemically during curing. They are said to be thermoplastic, because they can be softened by heat or by solvent. Chemically curing coatings are said to be thermosetting, because they are not softened by heating or by solvent. Air-oxidizing coatings (oil-based paints) are thermoplastic after initial curing. Upon further curing (e.g., 6 months or more), the additional polymerization (cross-linking of polymers) slowly converts them to thermosetting coatings. This is shown below:

<u>Thermoplastic Coatings</u>	<u>Thermosetting</u>
Lacquers	Chemically Reacting Products
Latex Products	Oil-Based Products (After Aging)
Oil-Based Products (Initially)	

2.2.1 Air Oxidation of Drying Oils. For coatings that cure by air oxidation of drying oils (usually vegetable), oxygen from the air reacts with unsaturated fatty acids in their drying oils. By this reaction, liquid resins are converted to solid films. Metal driers are usually incorporated into formulations of drying oil coatings to accelerate their normally slow curing.

a) Examples of coatings that are cured by this mechanism are:

- (1) Unmodified drying oils
- (2) Alkyds
- (3) Silicone alkyds
- (4) Epoxy esters
- (5) Oleoresinous phenolics

b) Such coatings wet surfaces very well and generally perform well in mild atmospheric environments, but they have limited durability in chemical environments, particularly alkaline environments. Epoxy esters provide some additional chemical resistance. They should not be confused with higher performance, two-component, chemically reacting epoxies. Oleoresinous phenolic coatings are the only oil-based coatings that can be used successfully in water immersion service.

c) Formulating oil-based coatings with low-solvent content presents difficulties and requires major formulation changes from those used for high-solvent coatings. Thus, attempts are also being made to develop waterborne alkyd products.

2.2.2 Solvent of Water Evaporation. Coatings that cure by simple evaporation of organic solvent are sometimes called lacquers. They are made by dissolving solid resins in an appropriate solvent. After application of a lacquer, the solvent evaporates to deposit the resin in a thin film. No chemical change occurs in the resin.

a) Examples of coatings that cure by this mechanism are:

- (1) Shellacs
- (2) Vinyls (polyvinyl chlorides)
- (3) Chlorinated rubber
- (4) Acrylics
- (5) Bituminous coatings (coal tars and asphaltics)

b) Coatings of this type have poor solvent resistance, since they are deposited from a solvent, but are easy to topcoat and repair because the topcoat solvent bites into the undercoat to bond tightly. Because lacquers are high in solvent content, that is, volatile organic compounds (VOC), their use has been greatly curtailed.

c) Latex and many other waterborne coatings also cure by simple water evaporation. Emulsified particles of solid resin coalesce to form a film as the water is lost. These coatings usually contain some organic solvent to control curing and improve application properties. Latex films are quite flexible and tend to be more permeable than oil and alkyd films. Examples of latex coatings are:

- (1) Acrylics
- (2) Vinyls (polyvinyl acetates)

d) At this time, it is important to point out that there are other types of waterborne coatings that cure by mechanisms other than simple water evaporation. The three basic types of waterborne coatings are:

- (1) Water soluble (of limited value)
- (2) Water reducible
- (3) Emulsions

e) Water soluble coatings are not durable enough for general use. The other two types of waterborne coatings find use on military facilities, although they may be somewhat less durable in some environments than corresponding solvent-based types. Water-reducible coatings contain a solvent blend that can be thinned with water. Alkyd and epoxy formulations are available in either water-reducible or emulsion forms. Such alkyd films are cured by air oxidation, and two-component epoxy films by chemical reaction.

2.2.3 Chemical Reaction. Coatings that cure by chemical reaction are usually the most durable. They are generally packaged in two separate containers that are mixed to initiate the reaction. Components must be combined in the specified proportions in the manner specified by the supplier to achieve a film with optimum properties. Sometimes, an "induction period" is required after mixing and before application to permit the reaction to get started. After mixing, there is always a "pot life" during which the coating must be applied, before the reaction has advanced so far that the coating cannot be properly applied.

a) Examples of coatings that cure by chemical reaction are:

- (1) Epoxies
- (2) Coal tar epoxies
- (3) Polyurethanes
- (4) Polyesters

b) Because these coatings are thermosetting, they have excellent chemical and solvent resistance. They are difficult to topcoat when fully cured, because topcoat solvent cannot bite into the films. Thus, a topcoat is best applied while the undercoat still has some residual tack. If a completely cured thermosetting coating is to be topcoated, it is necessary to first spray a thin (e.g., 2 mil wet film thickness) tie coat (tack coat) of the topcoat and allow it to cure to a tacky state.

c) Another example of a chemically curing coating is an inorganic zinc coating. Different formulations may cure by different types of reaction. Usually the cure reaction involves the hydrolysis (reaction with water vapor from the atmosphere) of the silicate binder. Some cure by reaction with water from the air, and thus cure slowly in dry environments. A one-package water-based inorganic zinc coating cures by chemical reaction after evaporation of the water.

d) Zinc-rich organic coatings, on the other hand, cure by the mechanism of curing of their organic binders. Thus, zinc-rich epoxies cure by chemical reaction and zinc-rich vinyls, by solvent evaporation.

2.3 Properties of Different Generic Types of Coatings. The properties of coatings commonly used on military facilities will be discussed individually below and then their properties will be summarized in a series of tables. Special mention will be made of the ease of formulating each generic type with a low VOC (solvent) content, since new restrictions on VOC content may limit or eliminate their use.

2.3.1 Alkyds and Other Oil-Containing Coatings. The unmodified drying oil coatings initially developed were very easily applied, did not require a high level of surface preparation, and had good flexibility; they could readily expand and contract with the substrate. They did, however, have several drawbacks: they were slow to dry, had residual tack, and provided a limited period of protection. They cannot be used in sea water immersion service or on alkaline substrates (e.g., concrete), because they are easily hydrolyzed (deteriorated by reaction with water) by alkalinity. They are used most on wood and steel surfaces.

a) Alkyd coatings, prepared by chemically modifying drying oil formulations, cured much faster than the unmodified ones and did not have residual tack. They retained the good application properties, but lost some flexibility. Silicone alkyds were developed by incorporating silicone into the resin to provide greater gloss retention. Epoxy esters were another modification of drying oils that improved some performance properties, particularly their chemical resistance, but worsened others, such as gloss retention. Still, none of these were suitable for a severe environment such as sea water. Oleoresinous phenolic drying oil formulations could be successfully used in water immersion.

b) Air-oxidizing coatings have limited solvent resistance. They continue to oxidize and cross-link after initial drying and curing. Thus, with time, they become harder, more brittle, and less soluble in solvent. That is, they become more like thermosetting coatings and are harder to recoat and maintain.

c) Although alkyds have long been the most widely used type of protective coating, their use is dropping rapidly because of difficulties in preparing formulations with: low VOC content, a brushable viscosity, and good film properties. Exempted halogenated hydrocarbons are presently being used to produce limited low-VOC alkyd formulations, but this exemption is expected to be withdrawn in the near future.

#### Alkyd and Most Other Air-Oxidizing Coatings

<u>Advantages</u>	<u>Limitations</u>
Easy to apply/repair/topcoat	Relatively high in VOCs
Good initial flexibility possible	Poor performance in severe environment
Good surface wetting/adhesion	Poor chemical/solvent resistance
Good gloss retention	Poor immersion resistance
Relatively inexpensive	Poor alkali resistance
Based on renewable source	Poor heat resistance
	Become brittle with extended aging

2.3.2 Water Emulsion (Latex) Coatings. Water emulsion coatings, commonly called latex coatings, have been successfully used for many years to coat wood and masonry structures. The porous nature of their films allows water vapor to pass through them, i.e., they are breathing. This porosity reduces their durability on steel. Thus, much effort is being made to develop more durable products because of the great advantages of their low VOC contents and ease of application and clean-up. In addition, water-emulsion coatings have excellent flexibility and low cost, and are easily topcoated and repaired. Drawbacks include poor solvent and heat resistance (as with all thermoplastics), poor immersion resistance, and difficulty in bonding to smooth oil/alkyd coatings and chalky surfaces. The poor bonding is due to insufficient content of organic solvents to soften and wet the binder in the existing paint film. Because of this limited adhesion, it is necessary to sand smooth enamels and/or use a surface conditioner before topcoating with latex

coatings. Also, latex paints do not cure well at temperatures below 50 degrees F, as the emulsion does not coalesce to form a good film.

### Water Emulsion (Latex) Coatings

<u>Advantages</u>	<u>Limitations</u>
Environmental acceptability	Limited durability
Easy to apply/repair/topcoat	Poor chemical/solvent resistance
Excellent flexibility and color and gloss retention	Poor wetting of surfaces
Low cost	Poor immersion service
Available in wide range of color and gloss	Must cure above 50 degrees F

2.3.3 Lacquers. Lacquers (e.g., vinyls, chlorinated rubbers, and acrylics) form durable films that have good water and chemical resistance but, being thermoplastics, poor solvent and heat resistance. They have a low film build but dry so fast that they can be quickly topcoated. When used on steel, they require a blast-cleaned surface, and in some cases wash priming, for good adhesion. They are easy to topcoat and repair and can be formulated for good gloss retention. The good weathering of acrylic lacquers is duplicated in acrylic water emulsion coatings.

a) The chief disadvantage of lacquers is their high VOC content. Because of their uniquely excellent performance on exterior concrete swimming pools, chlorinated rubber coatings have been granted temporary exemptions in some localities for this use despite their high VOCs.

### Lacquers (Vinyls, Chlorinated Rubbers, and Acrylics)

<u>Advantages</u>	<u>Limitations</u>
Rapid drying and recoating	High in VOCs
Good chemical resistance	Poor solvent/heat resistance
Good in water immersion	Low film build
Good gloss retention possible	Blasted surface necessary
Good durability	Occasional poor adhesion
Easy to topcoat and repair	
Can be applied at low temperatures	

b) Bituminous (asphalt and coal tar) coatings are also lacquers, but they are discussed separately because of their unique film properties. Bituminous coatings have found much use



in the past because they were inexpensive and easy to use. They have good water resistance but weather poorly in sunlight. They are used much less now because of toxicity concerns and their limited durability.

### Bituminous Coatings

#### Advantages

Low cost  
Easy to apply/repair/topcoat  
Good water resistance  
Good film build  
Low level of surface preparation

#### Limitations

High in VOCs  
Poor solvent/heat resistance  
Poor weathering  
Black color only

2.3.4 Epoxy Coatings. Epoxy coatings are two-component thermosetting products. (Epoxy-ester coatings are modified oil coatings, refer to par. 2.3.1.) One part is commonly called the base and the other, the catalyst component, although they are both best described as coreactants. Epoxies are available in a variety of formulations. Those most commonly used in general service are the epoxy polyamide (which has better water resistance) and the amine-cured epoxy (which has better chemical resistance). Epoxies and polyurethanes provide the best overall combinations of film properties of any organic coatings.

a) Epoxy films are tough and relatively inflexible. Thus, they cannot expand or contract much without cracking. However, they bond well and are very durable in most environments. They require a blasted steel surface, and they chalk freely in sunlight. An aliphatic polyurethane finish coat is usually applied when the coating is exposed to sunlight. Epoxies can be formulated to be low in VOCs, some actually solvent-free.

b) Epoxies, as do all thermosetting coatings, have topcoating problems. Solvent from a topcoat cannot penetrate a fully cured epoxy to bond tightly to it. Thus, a topcoat of a multiple coat system is applied when the undercoat is still somewhat tacky (e.g., within 4 days). If this is not possible, a fog coat (thin coat of about 2 mils wet film thickness) is first applied by spray and allowed to cure to a tacky state (e.g., 4 hours) before a full coat is applied.

Epoxy CoatingsAdvantages

Low in VOCs  
 Good solvent/water resistance  
 Tough, hard, smooth film  
 Good adhesion  
 Good abrasion resistance

Limitations

Limited pot life  
 Chalk in sunlight  
 Cure best above 50 degrees F  
 Topcoating is a problem  
 Blasted surface needed

2.3.5 Coal-Tar Epoxy Coatings. Coal-tar epoxy coatings are basically epoxies (with all properties of epoxies) to which coal tar has been incorporated. The coal tar reduces cost, improves water resistance, and provides for greater film builds. Because of the coal tar, coatings tend to become brittle in sunlight, and there is great concern about toxic effects of the coal tar. They are used primarily on steel piling and other buried structures. The catalyst component is usually either a polyamide or an amine.

Coal-Tar Epoxy CoatingsAdvantages

Low in VOCs  
 Good water/chemical resistance  
 Good film build  
 Good abrasion resistance

Limitations

Toxic; personal protection needed  
 Limited pot life  
 Blasted surface needed  
 Topcoating is a problem  
 Available only in black, dark red, or aluminum

2.3.6 Polyurethane Coatings. Polyurethane coatings are one- or two-package systems. For two-package systems, one component is an isocyanate and the other a polyol component. Because of the reactivity of the isocyanate, polyurethanes are moisture sensitive, and the gloss may drop when the wet film is exposed to high humidity. One component types cure with moisture supplied from the atmosphere. The toxicity of the isocyanate component is of great concern, and personal protection, including respirators, must be used when applying them. They require skilled applicators. Polyurethane coatings are available in a variety of formulations, giving rise to a variety of properties (e.g., may be tough or elastomeric). They perform well in most environments. Aliphatic polyurethanes have excellent weathering in sunlight; aromatic polyurethanes do not, but they have better chemical resistance. Both types can readily be formulated to be low in VOCs.

Polyurethane CoatingsAdvantages

Low in VOCs  
 Good solvent resistance  
 Good hardness or flexibility  
 May have excellent gloss  
 Good durability  
 Good abrasion resistance

Limitations

Highly toxic; need personal protection  
 Moisture sensitive; gloss may drop  
 Skilled applicator needed  
 Limited pot life  
 Blasted surface required  
 High cost

2.3.7 Polyester Coating. Polyester coatings are used most with fiberglass or glass flake reinforcement. They can be very tough and durable but are seldom used today on military facilities except with glass reinforcement.

2.3.8 Inorganic Zinc Coatings. Inorganic zinc coatings usually have a silicate resin and may cure by several different mechanisms. They can be formulated to be acceptably low in VOCs, particularly the water-based products. The silicate film is very hard and abrasion resistant. When applied too thickly, they may mud crack. Thus, they are generally applied at less than 5 mils dft, although some products can successfully be applied at greater thicknesses. They provide cathodic protection to steel, but as the zinc corrosion products fill the natural film porosity, they begin to provide barrier protection. If this barrier is broken by impact, cathodic protection will again take over until the break is healed by again filling with zinc corrosion products. They require greater steel surface cleanliness than do other coating types. They must be applied by a skilled applicator using a constantly agitated pot to keep the heavy zinc particles suspended. Inorganic zinc silicate coatings frequently do not bond well to each other, and it is safest to repair them using a zinc-rich organic coating. Problems may occur when topcoating them with organic coatings. Small bubbles of air or solvent vapors escaping from the porous silicate film may create holidays. Because of this concern, and their good performances without topcoating in a variety of services, it is often best not to topcoat them.

Zinc-rich organic coatings require less surface preparation and are easier to topcoat than inorganic zinc products. However, if properly applied, inorganic zinc coatings are extremely durable in an atmospheric environment, the steel preferentially receiving cathodic protection from the zinc. The zinc is attacked, however, by acid and alkali (i.e., is

amphoteric). Inorganic zinc coatings have not been used often in continuous water immersion because of concern for their limited period of protection.

### Inorganic Zinc Coatings

#### Advantages

Can be low in VOCs  
Excellent abrasion resistance  
Excellent heat resistance  
Good atmospheric durability  
Useful as shop primer  
Costly

#### Limitations

Needs clean, blasted surface  
Requires skilled applicator  
Constant agitation needed  
Difficult to topcoat  
Attacked by acid and alkali

2.3.9 Zinc-Rich Organic Coatings. Zinc-rich organic coatings utilize an organic resin rather than an inorganic silicate binder. Zinc-rich organic coating films can be of the thermoplastic (e.g., utilize vinyl or chlorinated rubber resins) or the thermosetting type (e.g., utilize epoxy or polyurethane resins). Film properties of zinc-rich organic coatings are similar in most respects to those of zinc-free organic coatings using the same resin. Organic zinc-rich coatings do not require as high a level of blast-cleaned steel surface as do zinc-rich inorganic coatings, and they are easier to topcoat.

### Zinc-Rich Organic Coatings

#### Advantages

Can be low in VOCs  
Good durability  
Relatively easily topcoated  
Moderate surface preparation needed

#### Limitations

requires skilled operator  
Constant agitation necessary  
Unsuitable for acid or alkali  
Costly

2.4 Coating Compatibility. Because of their different chemical and physical properties, coatings of different generic types or with different curing mechanisms are generally incompatible with each other. Those of the same generic type or with similar curing mechanisms are generally compatible with each other. Table 1 lists compatibilities and incompatibilities of different generic types of coating.

Another way to check solvent compatibility is to determine its solvent solubility. To do this, soak a cloth in methylethyl ketone or acetone, rub it against the existing paint, and visually check for pickup of paint. The paint is classified as "solvent soluble," if paint is picked up and as "solvent

insoluble," if not. Solvent soluble coatings are generally not compatible with coatings having strong solvents such as epoxies and polyurethanes.

A more system-specific way to determine compatibility of a new coating with an existing one is to apply a small patch of the new paint over the old one. If any of the incompatibilities described below exist, it will become visually apparent on the patch within a few days. Incompatibilities associated with differing mechanical properties (e.g., a more rigid coating over a more flexible one) or sensitivity to alkaline conditions occur in a longer timeframe and are also discussed below.

2.4.1 Bleeding. Bleeding (staining) may occur when a coating with a solvent is applied over an existing bituminous (coal tar or asphalt) paint or pavement. The solvent dissolves the bituminous material and permits it to spread through the topcoat to cause a brown surface discoloration. This normally does not adversely affect the film properties but produces an unsightly appearance.

2.4.2 Disbonding of Old Paint. Strong solvents in a topcoat may penetrate the existing undercoat and reduce its adhesion to the substrate. This may then result in disbonding of the total coating system from the substrate.

2.4.3 Topcoat Checking. An incompatibility may occur when a relatively rigid topcoat is applied over an existing flexible coating. If the topcoat checks (cracks in the topcoat only) to relieve the stress.

2.4.4 Poor Adhesion of Latex Topcoats to Enamels. Problems are frequently encountered in obtaining good bonding of latex topcoats to chalky surfaces or smooth fully-cured alkyd enamels. There is usually insufficient organic solvent in the latex topcoat to dissolve sufficient enamel to bond tightly to it. It may be necessary to first lightly sand the enamel to provide more texture for adhesion and/or apply an oil-based primer as a tack coat, before applying the latex topcoat.

2.4.5 Oil-Based Paints Applied to Alkaline Surfaces. Moist alkaline conditions cause a slow breakdown of oil-based paint films. The chemical reaction is called hydrolysis or saponification. The rate at which this occurs and the resulting rate of coating deterioration depend upon the environmental conditions and the specific formulation of the materials. However, in time oil-based coatings applied to alkaline surfaces will delaminate and peel.

Table 1  
Compatibility of Commonly Used Paints  
(Primer or existing coating less than 6 months old.)

Primer or Existing Coating	Topcoat										
	Oil Drying			Latex		Solvent Drying		Chemically Reacting			
	Oleoresinous	Silicone Alkyd	Alkyd	Acrylic	Polyvinyl Acetate	Vinyl	Chlorinated Rubber	Epoxy	Coal Tar Epoxy	Urethane	Polyester
Oil Drying											
Oleoresinous	C	C	C	CT	CT	NR	NR	NR	NR	NR	NR
Alkyd	C	C	C	CT	CT	NR	NR	NR	NR	NR	NR
Silicone Alkyd	C	C	C	CT	CT	NR	NR	NR	NR	NR	NR
Latex											
Acrylic	C	C	C	CT	CT	C	C	NR	NR	NR	NR
Polyvinyl Acetate	C	C	C	CT	CT	C	C	NR	NR	NR	NR
Solvent Drying											
Vinyl	C	C	C	CT	CT	C	C	NR	NR	NR	NR
Chlorinated Rubber	C	C	C	CT	CT	NR	C	NR	NR	NR	NR
Bituminous	NR	NR	NR	CT	CT	NR	NR	NR	NR	NR	NR
Chemically Reacting											
Epoxy	NR	NR	NR	NR	NR	CT	NR	CT	CT	CT	CT
Coal Tar Epoxy	NR	NR	NR	NR	NR	NR	NR	CT	CT	NR	NR
Zinc Rich Epoxy	NR	NR	NR	NR	NR	CT	CT	CT	NR	P	NR
Urethane	NR	NR	NR	NR	NR	NR	NR	NR	NR	CT	C
Polyester	NR	NR	NR	NR	NR	NR	NR	CT	NR	CT	CT
Inorganic Zinc	NR	NR	NR	CT	NR	CT	NR	CT	CT	P	NR

C = Normally Compatible.

CT = Compatible when special preparation and/or application conditions are met.

NR = Not recommended because of known or suspected problems.

P = A urethane may be used as a topcoat if its coreactant is polyether or acrylic, but not if it is polyester.

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## Section 3: ENVIRONMENTAL, OCCUPATIONAL, AND SAFETY ISSUES

3.1 Introduction. Environmental and health concerns have led to increased restrictions on coating operations. Material composition, surface preparation procedures, and application techniques have been affected. This chapter summarizes these restrictions and concerns. Detailed information on specific regulations related to these issues can be obtained from installation offices responsible for environmental, occupational, and safety issues.

3.2 Material Composition Issues

3.2.1 VOC Restrictions. VOCs make up the solvent portion of coatings. When emitted into the atmosphere, they may combine with oxides of nitrogen to form ozone, a major component of smog. The Clean Air Act of 1970 (amended in 1977 and 1990) requires states to develop and implement plans to ensure that the Environmental Protection Agency's (EPA) National Ozone Standard (less than 0.12 parts ozone/million parts air (ppm), by volume) is met (National Ambient Air Quality Standard, 40 Code of Federal Regulations (CFR) 50). To help meet this requirement, some states and regions have placed limits on the VOC content of paints and coatings.

3.2.1.1 Definition of VOC. For paints and coatings, VOC is defined as the amount of volatile organic material measured in a specific test procedure. The test procedure used in most regions is EPA Method 24 (40 CFR 60, Appendix A). The VOC content that is measured following such a procedure may be different from that calculated based upon the coating formulation. For field applied coatings, the VOC is determined on the coating as it is applied. That is, if the coating was thinned for application, the thinner contributes to the VOC level.

3.2.1.2 Types of Regulations. VOC regulations may place a limit on the VOC content of liquid coatings or the amount of VOC that a coating shop can release into the atmosphere, or may require a minimum transfer efficiency, depending upon the local regulations. VOC-content regulations vary from region to region within states and between states, depending upon the ability of a region or state to maintain compliance with the National Ambient Air Quality Standard for ozone. VOC-content regulations may apply to either or both shop-applied coatings and field-applied coatings (architectural). Many regions of the country have restrictions on shop-applied coatings, but only a few have restrictions on architectural coatings. (However, a national rule for architectural coatings is expected to become effective in 1996.) For military facilities, rules affecting shop-applied coatings (e.g., the miscellaneous metal parts rule) are of

greatest concern to the facility. The VOC limit for miscellaneous metal parts is 340 grams per liter (g/L) in most parts of the country. This limit is the result of a 1978 Federal EPA guideline for shop-applied coatings for metals (commonly called miscellaneous metal parts) which 35 states adopted as part of their state implementation plans for VOC control. Regulations that limit the total amount of organic materials released into the air by a coatings shop are also in effect in some areas of the country. Architectural coatings are regulated in California and some other regions of the country. In California, the acceptable limits are based on the type of structure to be coated (e.g., residential versus industrial) and coating type. For example, for most coatings for residential use, the limit is 250 g/L and for steel in corrosive environments, the limit is usually 420 g/L. Some special use coatings have higher or unrestricted VOC limits. Since these regulations are subject to change and since they vary from region to region, a general listing of which paints comply with local regulations is not presented.

3.2.1.3 Effect on Coatings. Traditional solvent-borne coatings, such as alkyds and epoxies, have been reformulated to meet the VOC regulations by using binders with lower viscosities, modifying the solvents or using other techniques to lower the VOC content. As examples, an epoxy, MIL-P-24441 has been reformulated to have a VOC content less than 350 g/L. New lower VOC content coating types have also been developed by using other coating technologies such as waterborne or powder. VOC-induced trends in coating selection are summarized below:

- a) Greater use of water-based paints
- b) Greater use of high-solids paints
- c) Less use of oil-based paints
- d) Elimination of lacquers (vinyls and chlorinated rubbers)
- e) Increased use of powder coatings

In general, to obtain an acceptable service life, a cleaner, better prepared surface is required for low-VOC content coatings than for traditional higher VOC content coatings. Application of low-VOC content field-applied coatings may also be more difficult than higher VOC content coatings.

Problems have been encountered with the use of some low-VOC content paints. They are summarized in Table 2.



Table 2  
Problems Encountered With Low-VOC Coatings

Generic Coating Type	Problems Observed
Oil-based	Longer drying time Residual tack or softness Poor leveling Wrinkling
Two-component epoxies	Reduced pot life Shortened drying time Settling Sagging Poor application properties
Polyurethanes	Reduced pot life Inability to apply thin films Reduced gloss

3.2.2 Application Issues. In some regions of the country, VOC emissions into the air have been further reduced by regulations restricting the methods of application of coatings to those with a minimum transfer efficiency of 65 percent. Transfer efficiency is defined as the percent of the mass or volume of solid coating that is actually deposited on the item being coated, as shown in the following formulas:

$$\begin{array}{l} \text{Transfer Efficiency} \\ \text{(Percent)} \end{array} = \frac{\text{Mass of Solid Coating on Item} \times 100}{\text{Mass of Solid Coating Consumed}}$$

$$\begin{array}{l} \text{Transfer Efficiency} \\ \text{(Percent)} \end{array} = \frac{\text{Volume of Solid Coating on Item} \times 100}{\text{Volume of Solid Coating Consumed}}$$

3.2.3 Toxic Solvents. Paints and coatings often contain solvents that are toxic at some level. While a person can withstand nominal quantities of most of these ingredients for relatively short periods of time, continuous or overexposure to them may have harmful effects. The potential severity of hazards is greatly magnified when operations are performed in enclosed or confined spaces where toxic solvent concentrations can quickly build up to levels which could produce disability and death. The threshold limit values (TLV) for several commonly used paint and cleaning solvents are given in Table 3. The TLV is a measure of the maximum concentration of solvent vapor in the air which can be tolerated during an 8-hour working day. Since these

concentrations are very low, they are expressed as parts of vapor per million parts of air by volume (ppm). The higher the value, the safer the solvent.

3.2.4 Hazardous Air Pollutants. Some solvents currently used in coatings are on the list of hazardous air pollutants of the Clean Air Act. Restrictions on the use of some of these solvents in coatings are expected. Also, halogenated solvents currently exempted from VOC restrictions because of their photo-chemical inactivity, may be eliminated from use in coatings in the near future because they deplete the upper atmosphere ozone layer. In addition, halogenated solvents can become explosive when in contact with aluminum spray guns.

3.2.5 Binders - Polyurethanes, Coal Tars, Asphalts. Coatings formulated with these resins may require special worker safety measures. Respirators and protective clothing may be needed. The material safety data sheet and the installation's health and safety office should be consulted.

3.2.6 Heavy Metal-Containing Pigments and Additives. Lead- and chromate-containing pigments have been used in paints to provide color and corrosion control. Because of health concerns, a Federal regulation limits lead concentration in new consumer paints to less than 0.06 percent of the weight of the paint solids. Although chromium, as chromate, is not specifically excluded from paints by Federal regulation, the military guide specifications for painting facilities (NFGS-09900, Paints and Coatings and CECS 09900, Painting, General) exclude chromate-containing coatings. Chromate is also on the ACGIH list of suspected carcinogens. Mercury-containing additives have been used to provide in-can bacteria control and paint-film mildew control. Because of health concerns, mercury can no longer be used in paints for residential use. Organic materials are used to control bacterial growth in the can and mildew growth on films.

Organo-tins have been used to control fouling on paints exposed to sea water. Because of the toxic effects of these materials, they have been restricted by the EPA. Copper-containing and some organic materials are being used to provide this protection.

Table 3  
TLV and Other Safety Data on Paint and Cleaning Solvents

Solvent	Relative Evaporation Time (1)	Flash Point (2) (deg F)	Evaporative Limits (3) (% by volume)		Threshold Limit Values (4)	
			(min)	(max)	TWA	STEL
Acetone	4	10	2.6	12.8	750	1000
Benzene (suspected carcinogen)	8	10	1.4	7.1	10	32
Butyl Alcohol (Butanol) - skin	70	105	1.4	11.2	50	
Carbon Tetrachloride - skin (suspected carcinogen)	8	not flammable			5	
Diisobutyl Ketone (DIBK)	150	140	0.8	6.2	25	
Ethyl Acetate	8	40	2.5	9.0	400	
Ethyl (Grain) Alcohol (Ethanol)	20	60	4.3	19.0	1000	
Ethyl Ether	1					
Ethylene Dichloride (1,2,dichloroethane)					10	
Ethylene Glycol Monoethyl Ether (Cellosolve) - skin	100	110	2.6	15.7	5	
Ethylenediamine - skin					10	
Ethylene Glycol Monoethyl Ether Acetate (Cellosolve Acetate) - skin	32	130	1.7	no data	5	
Hi-Flash Naptha (Aromatic)	105	105	1.0	7.0		
Isopropyl Acetate	10	50	1.8	7.8	200	250
Isopropyl Alcohol (Isopropanol) - skin	25	65	2.5	12.0	200	250
Methyl (Wood) Alcohol (Methanol) - skin	10	55	5.5	36.5	200	250
Methylene Chloride (Dichloromethane) (suspected carcinogen)	4	not flammable			50	
Methyl Ethyl Ketone (MEK)	8	30	1.8	10.0	200	300
Methyl Isobutyl Ketone (MIBK)	20	65	1.4	7.5	50	75
Mineral Spirits (Petroleum Thinner)	150	105	0.8	7.0		
Refined Kerosene	800	150	0.7	5.0		
Trichloroethylene					50	100
Toluene (Toluol) - skin	15	45	1.3	7.0	50	
Turpentine	100	105	0.8	no data	100	
VM & P Naptha	20	50	1.1	5.9	300	
Water	100	not flammable				
Xylene - skin	35	85	1.0	6.0	100	150

Table 3 (Continued)  
TLV and Other Safety Data on Paint and Cleaning Solvents

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NOTES: (1) Relative evaporation time is the relative time required for the solvent to completely evaporate, based on an arbitrary value of 1.0 for ethyl ether. The higher the number, the longer the time required for evaporation.

(2) Flash point is the temperature of the solvent in degrees F at which the solvent releases sufficient vapor to ignite in the presence of a flame. The higher the value, the safer the solvent with respect to flash point.

(3) Explosive limits define the range of solvent vapor concentration in air for which the vapor could explode or ignite. Below the minimum concentration and above the maximum concentration, the vapor will not ignite. These values are expressed as the percentage of the solvent vapor in the total volume of vapor plus air. They are also called flammable limits.

(4) Threshold limit values (TLV) were obtained from the American Conference of Governmental Industrial Hygienists (ACGIH), Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment. TWA is the time weighted average exposure limit for an 8-hour workday or a 40 hour week. STEL is the short-term exposure limit for a maximum 15-minute exposure. Both values are expressed as parts per million (ppm) of vapor per volume of air. The higher the value, the safer the solvent. These TLV's are ACGIH's recommendations; Occupational Safety and Health Administration (OSHA) limits may be lower.

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### 3.3 Issues Affecting Surface Preparation

3.3.1 Regulations. This section is aimed at environmental issues. Worker safety issues are discussed in Section 13. Environmental concerns and regulations affecting surface preparation activities involve contamination of the environment and waste disposal. Air regulations (National Ambient Air Quality Standards described in 40 CFR 50-99) that are closely associated with surface preparation and paint removal are the ones for air particulate matter (PM 10) and lead. Air particulate matter is defined as particles with an aerodynamic diameter less than a nominal 10 micrometers. The allowable limit is 150 milligrams per cubic meter, based on a 24-hour average concentration. For lead, the criterion is 1.5 milligrams per cubic meter, based on a 90-day average. Exceeding the PM 10 criterion is more likely during abrasive blasting than other coating operations.

To meet the air regulations described above, containment of work areas may be required. More extensive containment may be needed when removing lead-based paint. The Steel Structures Painting Council (SSPC) SSPC Guide 6I, Containing Debris Generated During Paint Removal Operations, describes five categories of containment. Worker protection must also be considered in designing containment and ventilation systems. Protecting both the environment and the workers is a challenging task.

3.3.2 Waste. Debris resulting from surface preparation may be hazardous waste as defined by Federal solid waste regulations (40 CFR 240-280). Waste may be classified as hazardous if it exhibits any of the following characteristics: ignitability, corrosivity, reactivity, or toxicity, or if it is on a special EPA list. For paint debris, wastes are most likely to be hazardous because of their toxicity (e.g., exceeds limits for lead, cadmium, chromium or mercury) or because of their corrosivity (e.g., pH greater than or equal to 12.5 or pH less than or equal to 2). For toxicity, waste is tested using the toxic characteristic leaching procedure (TCLP) test, described in Appendix II of 40 CFR 261. Waste is classified as hazardous because of toxicity if lead concentration in the leachate exceeds 5 mg/kg, cadmium concentration exceeds 1 mg/kg, chromium concentration exceeds 5 mg/kg, or mercury concentration exceeds 0.2 mg/kg. Paint debris wastes fail most often because of lead. Some industrial paint wastes have also been reported to fail because of chromium or cadmium. Although paint debris may contain low concentrations of mercury from old films in which mercury additives were used to control fungal or bacterial growth, experience indicates that paint waste is unlikely to fail because of mercury toxicity.

3.4 Surfaces Coated With Leaded Paint. The presence of lead in paint films causes health, environmental, and worker safety concerns. This section describes the DOD policy for dealing with leaded-paint associated problems and summarizes DOD guidance. References for specific guidance are given in the References section.

#### 3.4.1 Background

3.4.1.1 Use of Lead in Paint. Most oil-based residential paints contained lead pigments prior to 1940. Lead pigments provided hiding and color (tints of orange, yellow, green, and red). Lead driers were used in both pigmented oil-based paints and varnishes. The concentrations of lead in white or light-colored paints sometimes exceeded 50 percent of the mass of the dry film. Concentrations of lead in paints colored using lead pigments ranged from 1 to about 10 percent of mass of the dry

film. Lead driers were used in concentrations of a few tenths of a percent of the mass of the dry film. The use of lead hiding pigments decreased when titanium dioxide became available in the 1940's, but it was not until 1972 that a Federal regulation set the maximum allowable level of lead in residential paint transported interstate at 0.5 percent. This level was reduced to 0.06 percent for all residential paints in 1978. Thus, lead-based paint abatement is directed primarily at housing built prior to 1978. For steel structures, lead-containing primers (e.g., those pigmented with red lead) have been used on military facilities until recently to control corrosion. Yellow traffic marking paints also may contain lead.

3.4.1.2 Effects of Lead Exposure on Health. Lead can cause a variety of serious adverse health effects. These are detailed in the Strategic Plan for Elimination of Childhood Lead Poisoning, Center for Disease Control, 1991. In children, even low levels of lead increase a child's risk of developing permanent learning disabilities, reduced concentration and attentiveness spans, and behavior problems. Adverse health effects may occur before the appearance of any symptoms. Symptoms include loss of appetite, difficulty sleeping, irritability, fatigue, headache, moodiness, joint and muscle aches, and metallic taste in the mouth. High levels of lead concentrations can result in severe damage to the blood forming, nervous, urinary, and reproductive systems of the body. Lead poisoning from leaded paint typically occurs due to the ingestion of leaded paint or lead-contaminated dust into the body through the digestive system or inhalation. Peeling and chipping of leaded paint or abrasion of surfaces of leaded paint are primary pathways for lead poisoning.

3.4.1.3 Environmental Issues. Lead containing materials are a potential hazard to the environment when released in an uncontrolled manner. Proper containment of painting operations involving leaded paint and proper disposal of the debris are required to prevent contamination of soil, water and air. Debris generated during a maintenance painting job involving leaded paint may contain enough lead to be classified as a hazardous waste. If so, storage, transportation, treatment, and disposal of waste is governed by Federal regulations and applicable local and State regulations.

3.4.1.4 Occupational Safety Issues. Workers involved in leaded-paint removal are at risk for lead poisoning. Poisoning can result when the leaded paint is disturbed in a way that creates uncontrolled dust or small particles such as in sanding, open-abrasive blasting, chipping, grinding, and burning. The lead dust makes its way into an individual in many ways, including eating dust-contaminated food, hand-to-mouth activity, smoking cigarettes, and breathing dust-contaminated air. This

hazard was addressed by in a rule published May 4, 1993 in the Federal Register, 29 CFR Part 1926.62. This rule amended their regulations for construction workers. It reduced the permitted level of exposure to lead for construction workers from 200 micrograms per cubic meter of air as an 8-hour TWA to 50 micrograms per cubic meter of air. Special worker-protection requirements are mandated when surfaces coated with leaded paint are disturbed, unless existing data show that the requirements are not needed. Training for workers aimed at both residential and non-residential activities is available from EPA-sponsored training centers and other private training groups.

3.4.2 Definitions. For the purposes of this discussion, residential structures are Government owned or leased family housing, child development centers, family child care homes, schools, playgrounds, and similar facilities. Target residential facilities are those constructed prior to 1978. Facilities constructed or included in whole-house revitalization or similar major rehabilitation projects since 1978, if paint coatings were removed or replaced, are considered free of lead-based paint. Non-residential structures include office buildings, warehouses, water towers, and the like. Lead-in-paint terms are defined in the following way:

a) Leaded paint - paint containing lead compounds as an ingredient at potentially hazardous concentrations.

b) Lead-based paint - a legislative term, defined by the U.S. Lead-Based Paint Poisoning Prevention Act as existing paint in residential structures having lead concentrations of 1 milligram per square centimeter or greater.

c) Lead-containing paint - a regulatory term, defined by the Consumer Product Safety Commission as residential paint (wet) offered for sale having a lead concentration greater than 0.06 percent by weight of the film solids.

3.4.3 DOD Policy/Instruction. The following sections summarize policy documents issued by DOD and military components for residential and non-residential structures (Table 4).

3.4.3.1 Residential Structures. DOD's policy memorandum, Lead-Based Paint (LBP) - Risk Assessment, Associated Health Risk in Children, and Control of Hazards in DOD Housing and Related Structures, describes the DOD policy for residential structures. A DOD instruction will also be developed. The DOD policy is to provide occupants of DOD residential structures (to include leased structures) a safe and healthful environment. The memorandum covers 1) assessing health risk from LBP and 2) controlling LBP hazards in DOD housing and related structures.

The memorandum states that DOD will assess and correct all recognized health-hazards in DOD residential structures and will negotiate for assessment and control of LBP in DOD-leased facilities. Control of LBP will be by either in-place management (IPM) or removal. Removal is to be performed when IPM cannot reliably control the lead hazard, or when removal is cost effective during renovation or upgrade. Specific procedures for carrying out the DOD policy are described in each of the military component's documents shown in Table 4. The information is summarized in par. 3.4.4.

Table 4  
DOD and Military Component's Policy Documents on Lead-Based Paint

Document No.	Document Name	Scope	Point of Contact
DOD Memorandum, 24 Nov 1992	Lead-Based Paint (LBP) - Risk Assessment, Associated Health Risk in Children and Control of Hazards in DOD Housing and Related Structures	Residential	ODASD (Env/Sfty & Occ Hlth)
U.S. Army, Memorandum 28 April, 1993	Lead-Based Paint Policy Guidance	Residential	CEHSC-FB-S, Bryan J. Nix
U.S. Air Force, 24 May 1993, HQ USAF/CC	Air Force Policy & Guidance on Lead-Based Paint in Facilities	Residential and Industrial	HQ AFCEA\ENE, Barry Kollme
U.S. Navy, 9 Nov 1992 Memorandum 11101 FAC 08/T1822B	Navy Family Housing Lead-Based Paint/Asbestos Inventory Program	Residential	NAVFAC (Fam Hsg), Richard Hibbert
U.S. Navy, Design Policy Letter, DPL-09B-0001	Lead-Containing Paint on Non-Residential Structures	Non-Residential	NAVFAC Code 1004, Bruce Bell

3.4.3.2 Non-Residential. Although there is no corresponding DOD memorandum for non-residential structures, the Air Force, Army and Navy have policy documents, referenced above, which prohibit the use of lead-containing paint on non-residential structures. (The Navy allows a slightly higher amount of lead in coatings for corrosion control - less than 0.3 percent by mass of the dry film - to account for possible contamination of zinc pigments by lead.) The Navy policy also states that surfaces covered with intact leaded paint do not represent a hazard until there is a need to remove or physically disturb the existing paint. Whenever surfaces covered with leaded paint are



disturbed, for example during repair or as part of an operations and maintenance activity, special precautions may be required to ensure the safety of the workers and prevent contamination of the surroundings.

3.4.4 General Description of Lead-Based Paint Procedures. Identification, risk assessment, and abatement procedures for lead-based paint in residential and non-residential structures may not be the same because of the differences in the way the structures are used and maintained.

3.4.4.1 Inspection/Assessment. The first step of inspection/assessment is to prioritize facilities to ensure that those most likely to have the worst lead-based paint problems are inspected first. Next, painted surfaces (using the Department of Housing and Urban Development (HUD) guidelines list of components and surfaces) are inspected to identify lead-based paint, lead-containing dust or lead-based paint hazards. For paint, portable x-ray fluorescence devices are used in conjunction with limited sampling of surfaces for laboratory atomic absorption spectrometric analysis. The data are analyzed to determine which surfaces present a high risk (e.g., peeling, chipping) to occupants. Both IPM and removal are part of all the strategies. The objective of the IPM is to reduce excessive exposure to lead and protect occupants from lead poisoning in facilities pending total removal of lead-based paint.

For non-residential structures, there are no written procedures for choosing surfaces for testing for leaded paint. The primary circumstance in which paint is tested on non-residential structures is just prior to preparing a contract for maintenance painting. At that time it is important that samples be taken for laboratory analyses to determine whether the paint contains lead. This is because special worker safety and environmental controls may be needed during coating maintenance to protect workers and the environment. Environmental controls include containment of debris to prevent it from polluting air, soil, or water. Although there are no standard procedures for this inspection, it is important that enough samples be taken to obtain a representative lead concentration of the paint. All layers of the paint film must be included in the samples. Testing should also be undertaken prior to maintenance and operation activities that will cause significant amounts of leaded paint to enter the environment. Both worker safety and local containment of debris are of concern.

3.4.4.2 In-Place Management (IPM). IPM refers to a broad range of strategies and methods for controlling exposures to lead and preventing poisonings from lead in paint pending permanent removal. Because of the high number of facilities with lead-

based paint, immediate removal of all lead-based paint will not be possible. IPM includes cleaning up lead-contaminated dust, chipping, and peeling paint, and taking steps to stabilize lead-based paint to prevent additional peeling paint. IPM also includes monitoring surfaces painted with lead-based paint and appropriate periodic clean up of lead-contaminated dusty surfaces. It also requires maintenance and repair work be carried out with attention to the potential for creating lead hazards.

3.4.4.3 Removal. The Navy Guide Specification, NFGS-13283, Removal and Disposal of Lead-Containing Paint, and the Army Corps of Engineers Guide Specification (CEGS) 02090, Removal of Lead-Based Paint, provide guidance for removal of leaded paint in both residential and non-residential structures. The following issues must be considered for both types of structures:

- a) Occupant safety
- b) Building contents
- c) Worker safety
- d) Environmental protection (containment of debris)
- e) Cleanup
- f) Waste disposal

Detailed guidance for paint removal from residential structures can be found in the HUD guidelines. The SSPC has prepared three documents dealing with issues pertaining to removal of lead-containing paint from industrial structures: SSPC Guide 6I; SSPC Guide 7I, Disposal of Lead-Contaminated Surface Preparation Debris, and SSPC QP2, Evaluating the Qualifications of Painting Contractors to Remove Hazardous Paint.

3.4.4.4 Operations and Maintenance. Special operations and maintenance activities may disturb lead-containing paint, for example repairing a light fixture. In these situations, special precautions are needed to:

- a) Protect the worker
- b) Control the spread of the dust that is generated
- c) Ensure that debris is collected, handled, and disposed of properly

3.4.5 Waste Disposal. Wastes from some painting operations involving leaded paint may be classified as hazardous waste under the Resource Conservation and Recovery Act (RCRA). Regulations resulting from this act can be found in 40 CFR 240-280. For lead-containing wastes, these regulations require that a representative sample of the waste be tested using a standard procedure, the TCLP. If the amount of lead that is leached from the waste exceeds 5 mg/kg (ppm), the waste is classified as hazardous. In addition, if alkaline chemical strippers are used for removal, the waste may fail because of its alkalinity. If the debris is classified as a hazardous waste, special procedures are required for handling, transporting, treating and disposal. These requirements are described in detail in 40 CFR 260-268. The cost for disposing of hazardous waste is many times greater than for non-hazardous waste.

3.4.6 Demolition of Buildings Containing Lead-Based Paint. Maintenance painting is not directly involved in demolition of buildings containing leaded paint. However, sampling and testing procedures to determine whether debris is hazardous due to the presence of lead are similar. In addition, restrictions on sorting the waste into hazardous and non-hazardous groups are similar. Information on disposing of demolition debris is available in guide specification (Sampling Protocol - Building Demolition Debris and Buildings Painted With Lead-Based Paint) prepared by HSHB-ME-SH, U.S. Army Environmental Hygiene Agency, Waste Disposal Engineering Division, Aberdeen Proving Ground, MD 21010-5422.

3.4.7 Sources of Detailed Information. Details of procedures for removing, abating, and managing existing lead-based paint on surfaces can be found in the references listed below:

a) Lead-Based Paint: HUD Interim Guidelines for Hazard Identification and Abatement in Public and Indian Housing (can be obtained by calling 1-800-245-2691)

b) Air Force policy and guidance

c) Army policy and guidance

d) Navy policy and guidance